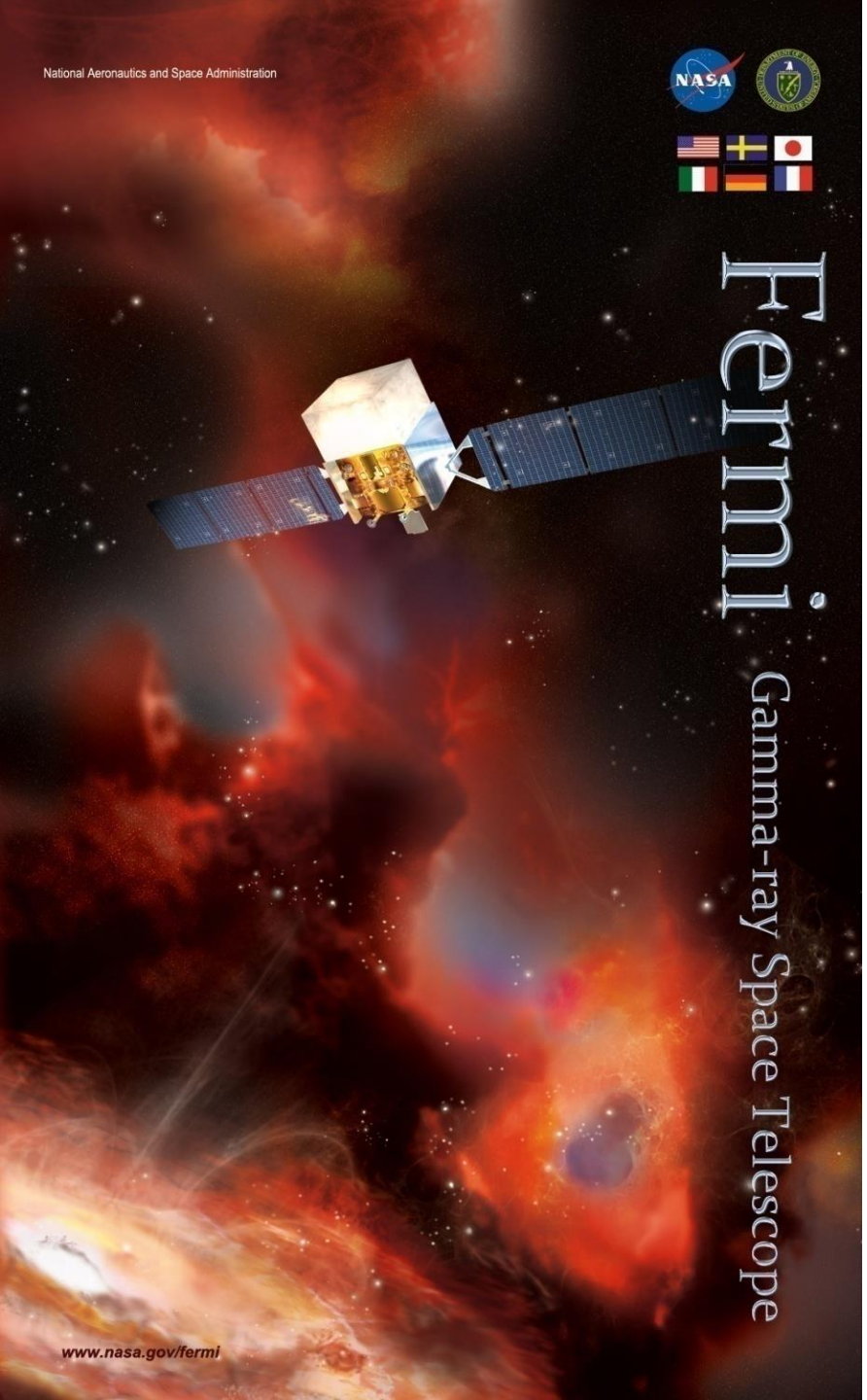

Multiwavelength monitoring of gravitationally lensed blazar QSOB0218+357 between 2016 and 2020

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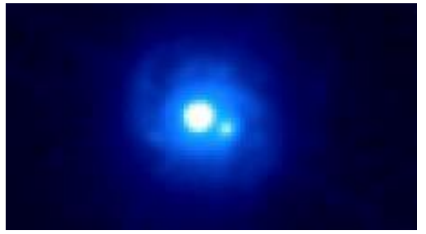
TevPa 2021

Outline

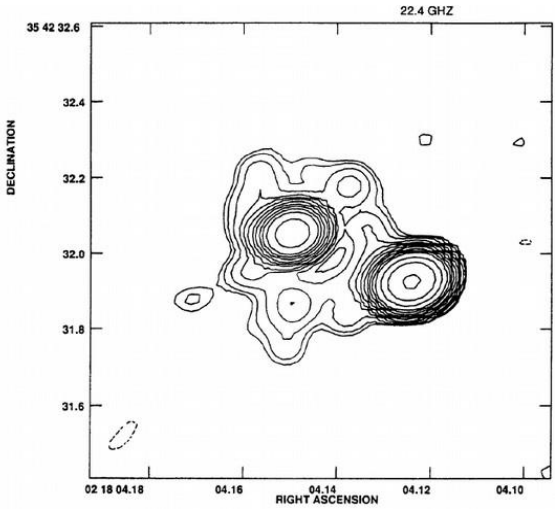
- Source details and previous γ-ray analysis
- LAT analysis setup
- MWL monitoring
- Lens modeling
- Absorption at the lens
- Modeling of the broadband emission

QSO B0218+357

- Distant FSRQ (z=0.94)
- Gravitationally lensed by a spiral galaxy seen face-on (z=0.68)
- Discovered with the NRAO 140 ft telescope in its strong source survey (S3 0218+35; Pauliny-Toth & Kellermann 1972).
- Radio imaging revealed its gravitationally lensed nature, with the smallest separation double-image known (335 mas) and an Einstein ring with a similar angular diameter (O'Dea et al. 1992; Patnaik et al. 1993).
- The emission is observed in two distinct images (visible in radio and optical), separated by ~ 11 days



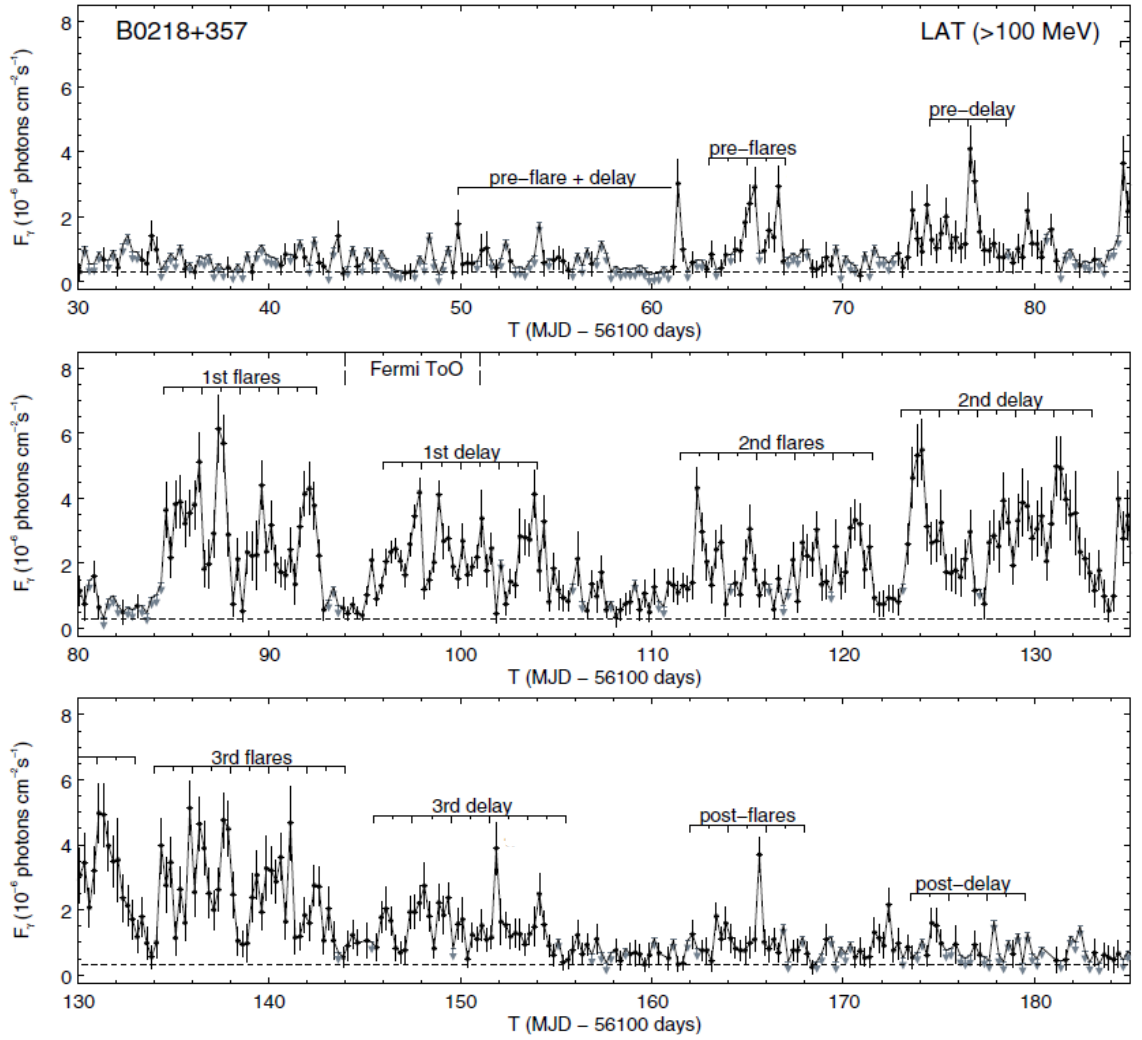
Hubble, NASA/ESA



O'Dea et al 1992

Fermi-LAT - 2012 flare

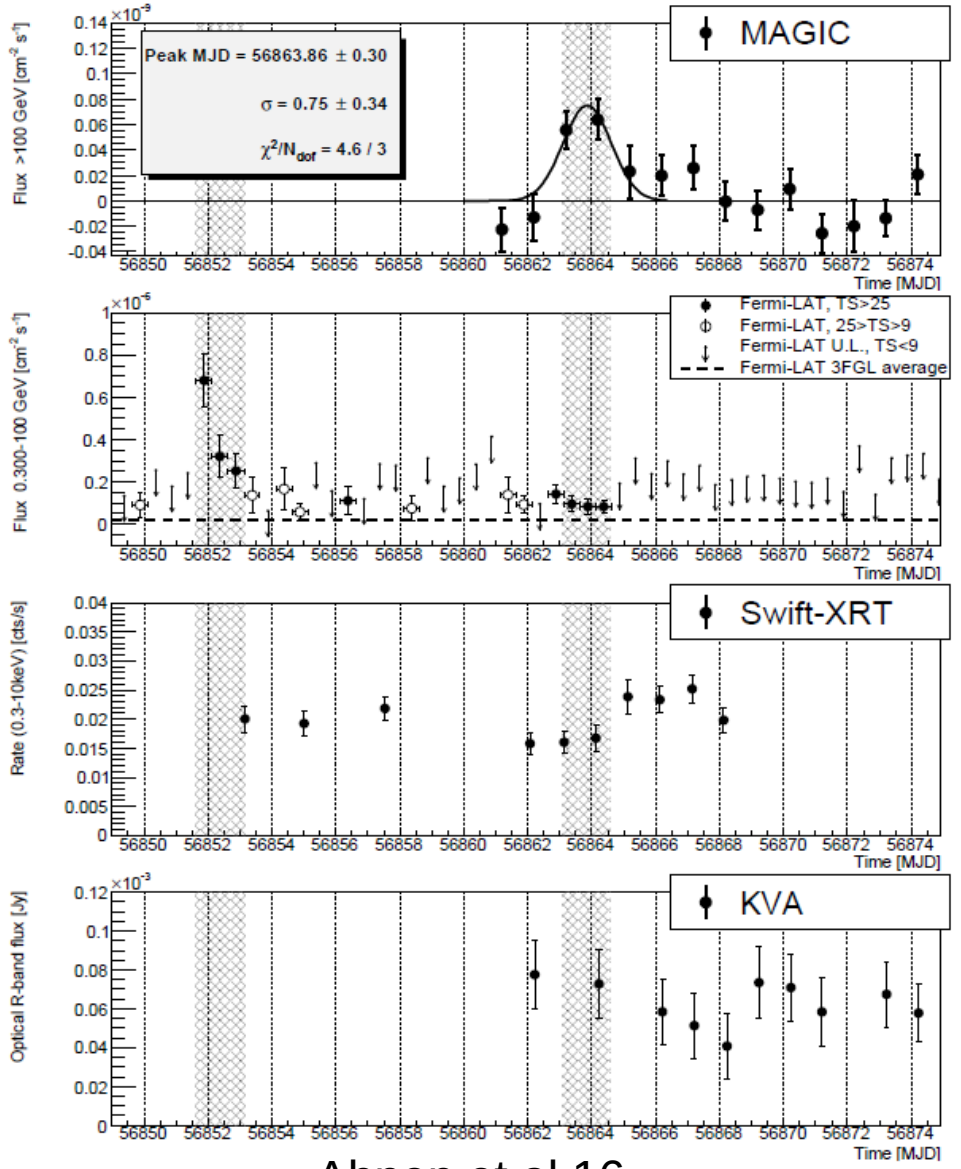
- The first clear γ-ray measurement of the delay between flares in Cheung. et al 2014
- In a period of enhanced γ-ray activity with peak fluxes >20–50 × the average
- Delay in the γ-ray data of 11.46 ± 0.16 days (1σ)
- Magnification ratio not clear, due to confusion in the integrated light curves



Cheung. et al 2014

Fermi-LAT & MAGIC - 2014 flare

- Another flaring state was observed by *Fermi*-LAT on 2014 July 13 and 14 (Buson & Cheung 2014).
- The delay between the two components is compatible with the previous measurement.
- Delayed image detected in VHE γ-rays by MAGIC in response to the *Fermi*-LAT detection (Ahnen et al 16)
- No measurement of the magnication ratio or delay could be obtained in VHE.



Ahnen et al 16

MAGIC monitoring

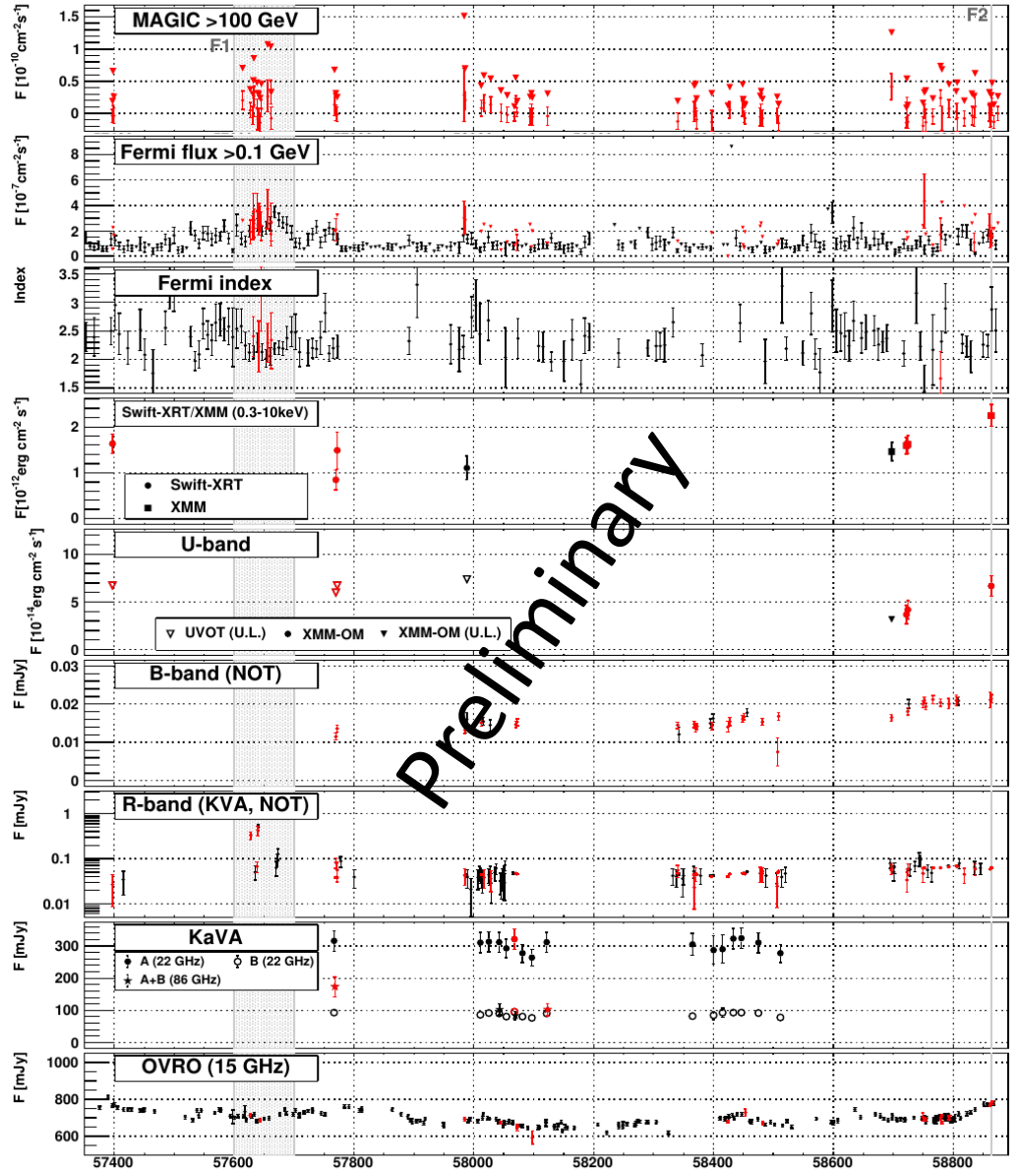
- In years 2016-2020 optimized MWL monitoring was organized to allow the observation of the same flare in both images
- Observational windows which allow visibility under favourable zenith angle conditions in moon-less nights 11 days after each slot has been identified.
- During these time MAGIC observations were performed, and contemporaneous multiwavelength (MWL) coverage from radio to GeV was obtained.

Fermi-LAT analysis setup

- SW: Science tools 1.2.23 & Fermipy 0.19.0
- IRFS : P8R3_SOURCE_V2 Energy: 0.1 GeV-2 TeV
- Whole time range analysis: MJD 56929-58876
- RoI: 15°
- Spectral model: LogParabola
- Background:
  - Galactic interstellar emission model: gll_iem_v07
  - Isotropic spectral template: iso_P8R3_SOURCE_V2_v1
  - point sources from the *Fermi*-LAT 8y Catalog (4FGL)
  - 4 new point sources found iteratively
- Weekly & Daily LC

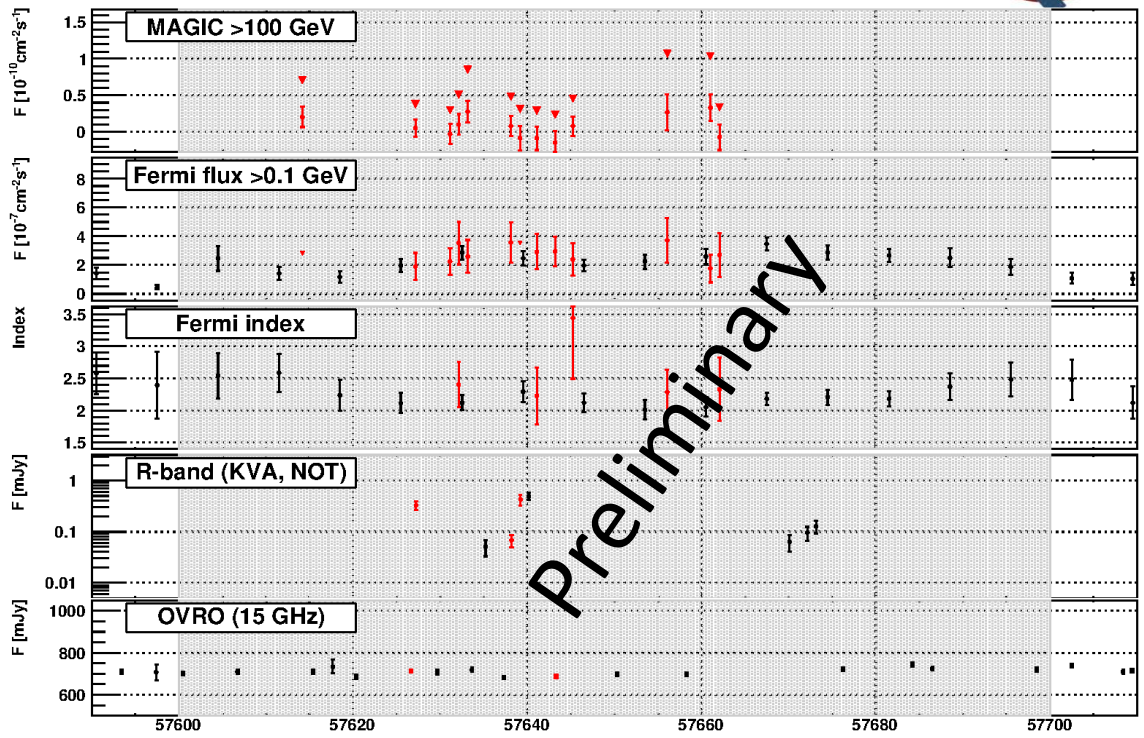
MWL monitoring

- Gamma rays: MAGIC, *Fermi*-LAT
- X-ray (Swift-XRT, XMM) – only a few pointings
- Optical: KVA, NOT
- Radio: OVRO 15 GHz
- Radio interferometry: KaVA 22-86 GHz
- **Flares and hints of enhanced emission in GeV range, optical and X-ray**



Enhanaced GeV and optical state

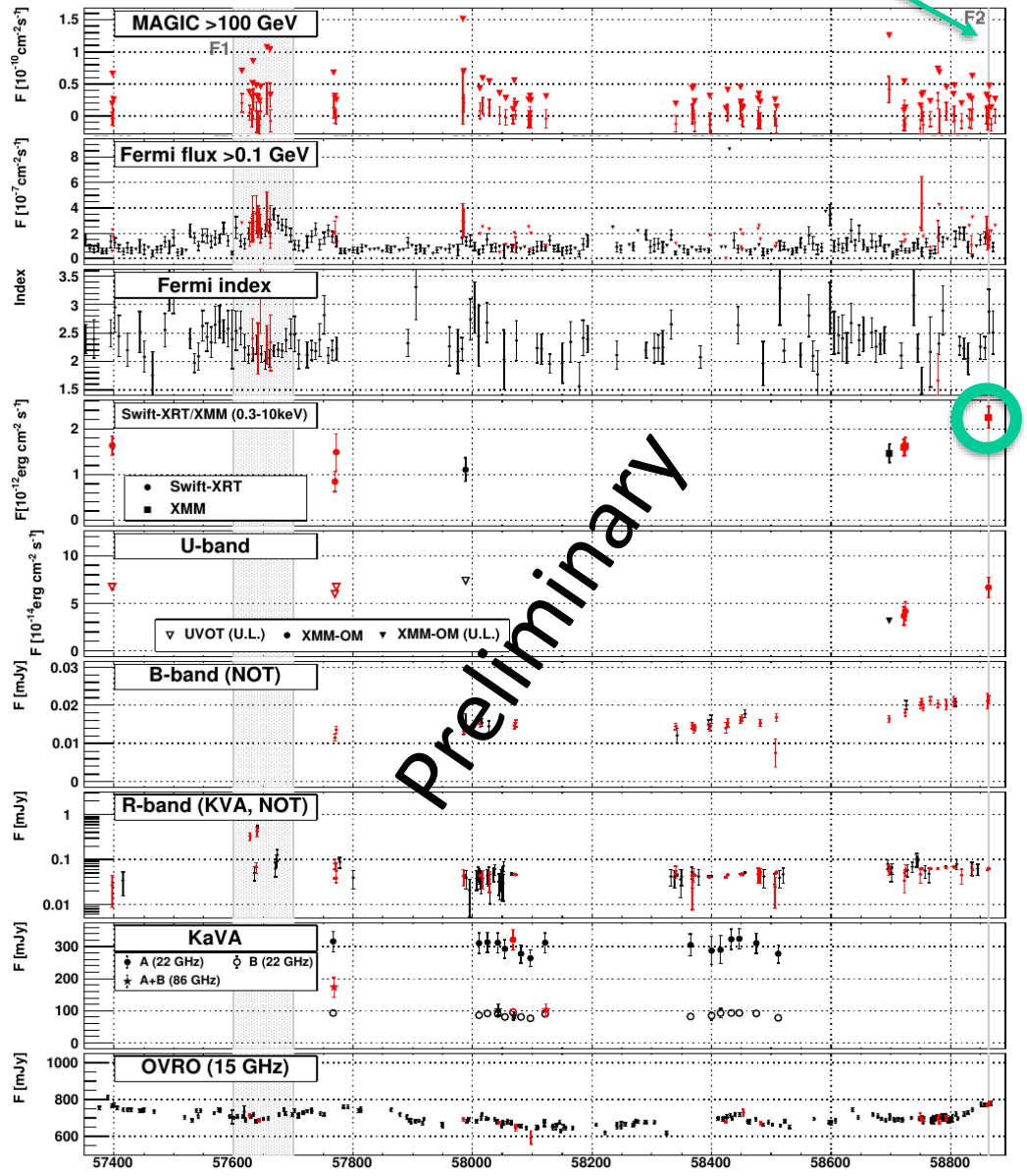
- A few months long high GeV state (around MJD~57650) during which short increase of optical flux by an order of magnitude was observed.
- Comparing to the 2014 flare:
  - the GeV emission is at a similar level but softer;
  - the optical emission is nearly an order of magnitude higher.
  - MAGIC Upper Limits two times below the level observed during the 2014 flare.



- The distance between the optical peaks is consistent with the one expected from lensing, but sparse sampling does not allow the optical delay to be measured.

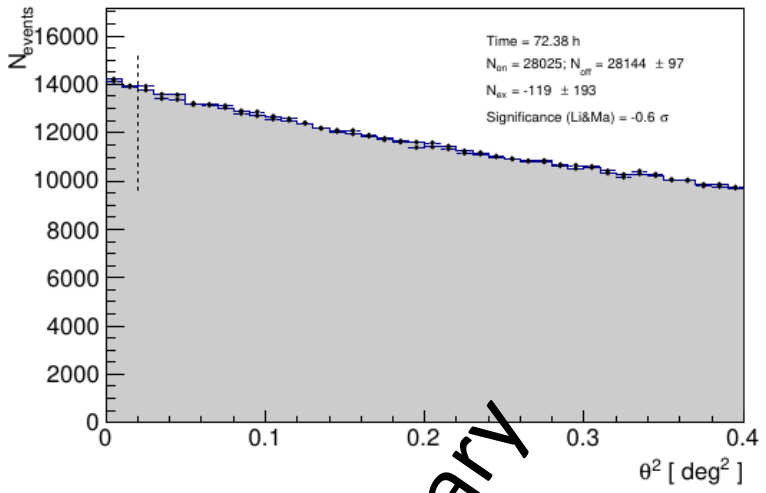
Hint of enhanced X-ray activity

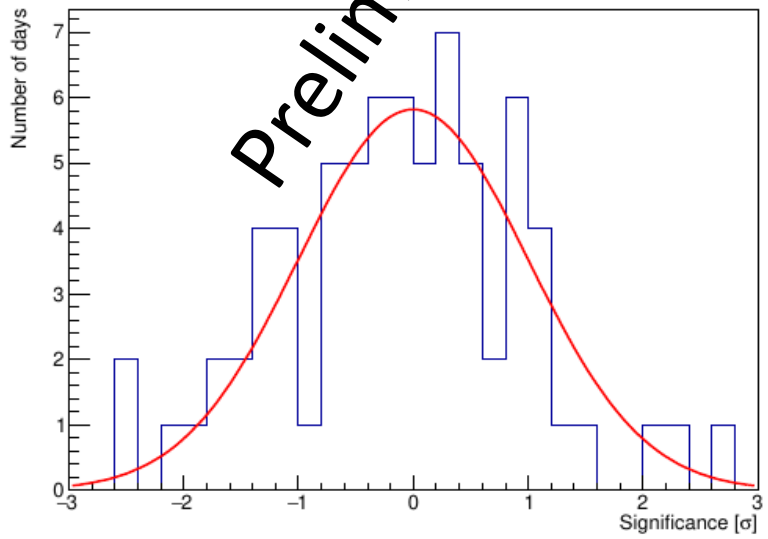
- A hint of enhanced X-ray activity was observed by XMM-Newton on MJD 58863.7.
  - The X-ray flux density increased by $(44 \pm 19)\%$ with respect to the previous measurements.
  - No excess of GeV flux and no significant detection from MAGIC
  - Optical flux density was constant
  - UV flux density increased by $(70 \pm 41)\%$



Search for VHE gamma-ray emission

- Deep exposure with MAGIC telescopes: 72hrs in 73 night
- No significant transient emission detected on any nights (including the nights of enhanced GeV, optical or X-ray activity)
- No detection of a low-state VHE gamma-ray emission

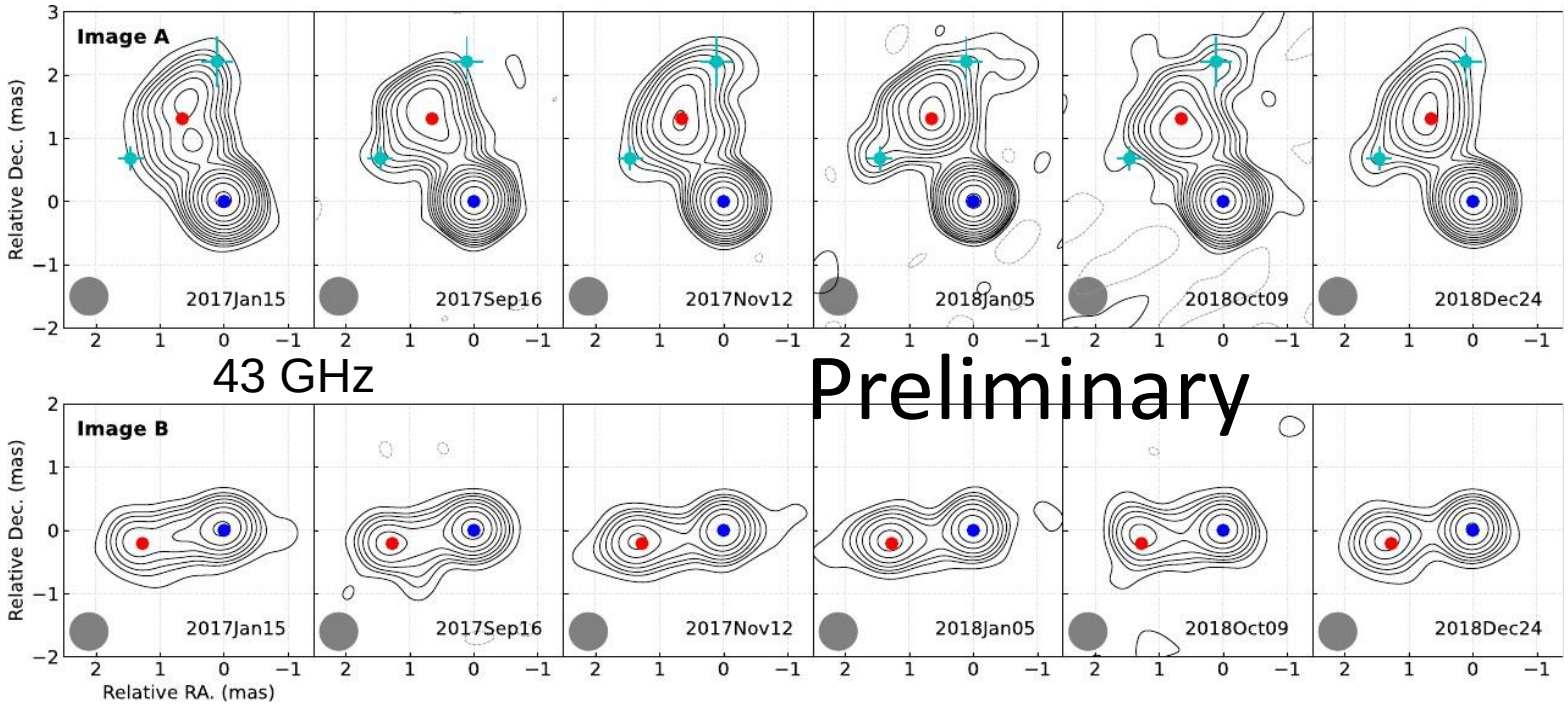




Preliminary

Radio image of the source

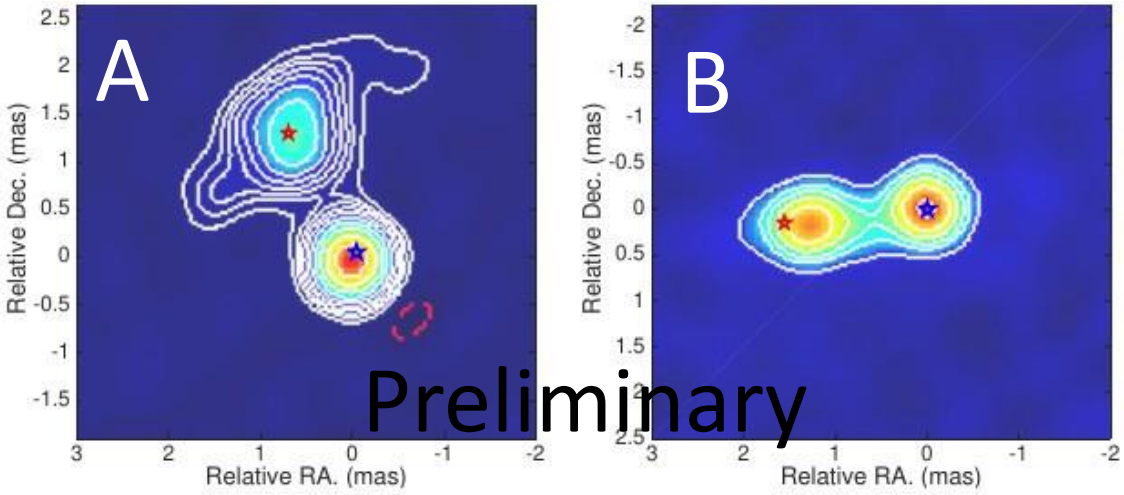
- Clear radio core and jet component seen in both radio images
- Projected distance from the core to the jet: 10 pc
- Sideways wings seen in the brighter (A) image



- No significant variability in flux or in position of the components in 2016-2019 measurements

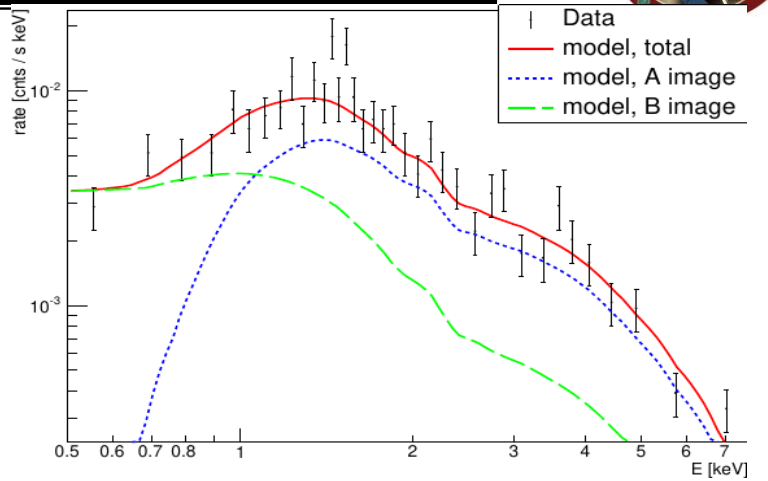
Lens model

- Radio images used to update lens model of the source
- The modeled positions of the lens images of the core and the jet agree within 0.034-0.26 mas
- Predicted magnification ratio: 3.81 for the core and 3.67 for the jet

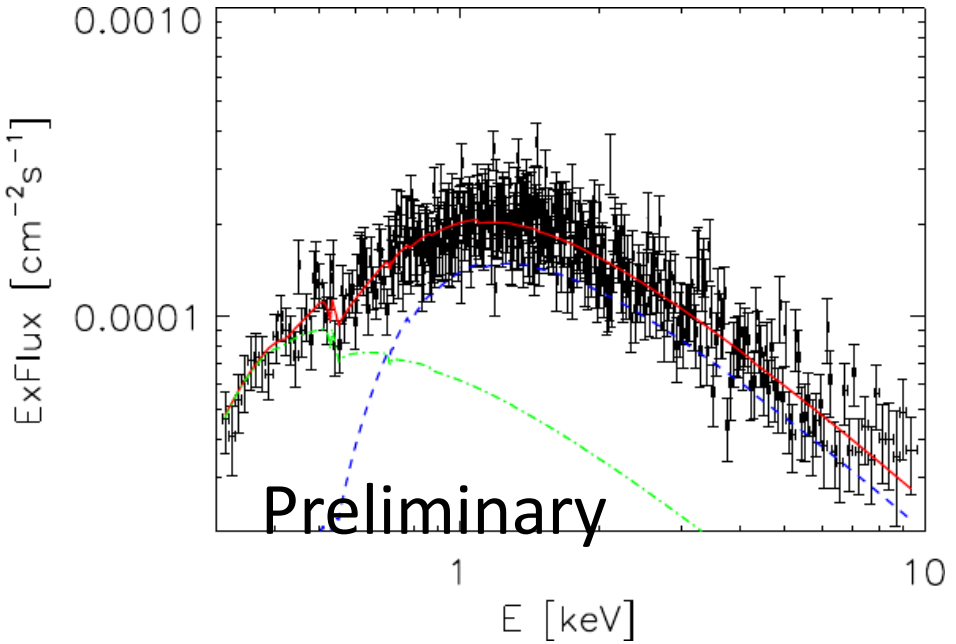


Absorption at the lens

- High quality X-ray spectrum of XMM is fitted by a combination of two A and B images of the source using derived magnification ratios and allowing for absorption at A image.
- Obtained column density of $(8.10 \pm 0.93) \times 10^{21}\ cm^{-2}$
- Previous measurements:
  $(24 \pm 5) \times 10^{21}\ cm^{-2}$(Swift-XRT, Ahnen et al. 2016)
  $(5 - 50) \times 10^{21}\ cm^{-2}$(molecular absorption line, Menten & Reid, 1996)



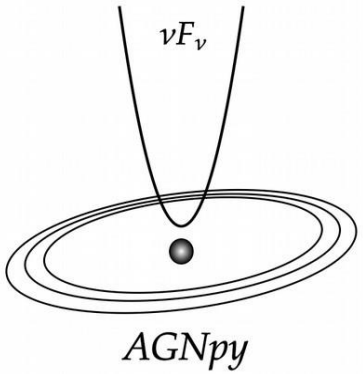
Swift-XRT data of 2014, Ahnen et al 2016



XMM-Newton monitoring data in low state

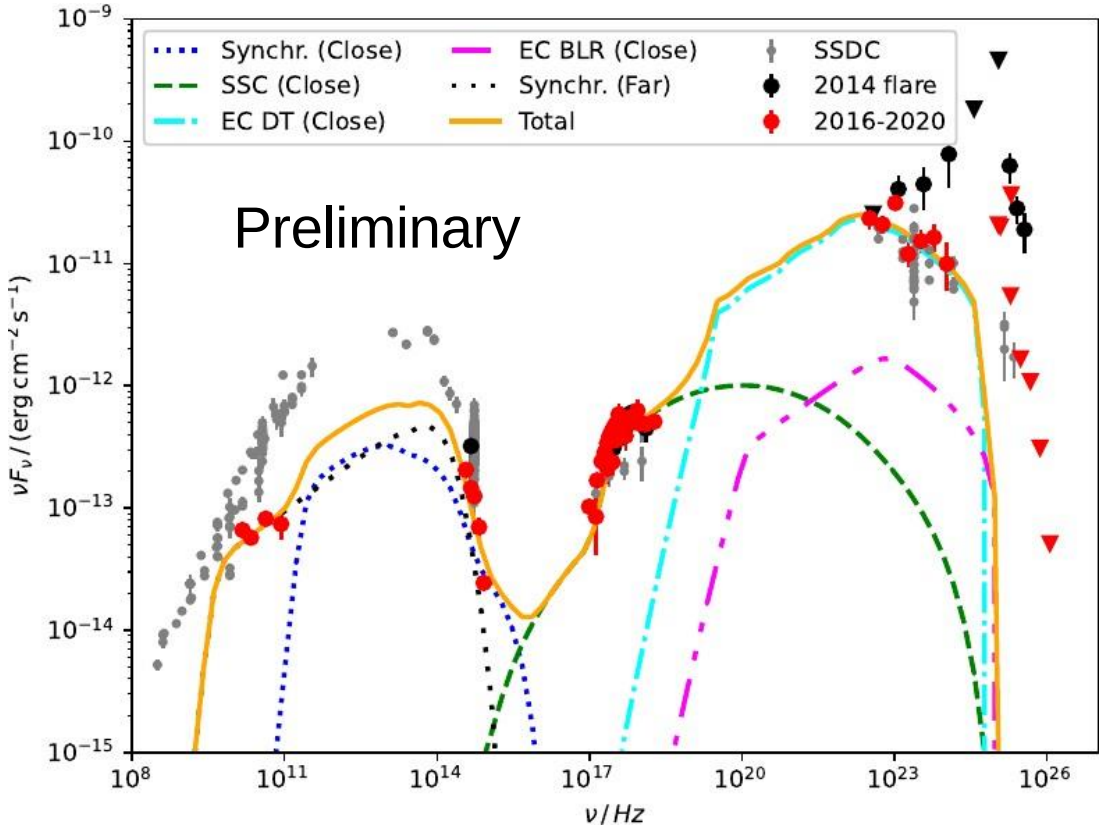
Modeling of the broadband emission

- Need to take into account:
  - Lensing magnification (sum of both images)
  - Absorption of optical-UV and X-ray (only A image)
- Modeling scenario typical for FSRQ: external Compton (on Dust Torus radiation field) with a possible Synchrotron Self-Compton (SSC) emission
- Second emission zone ("far", at 100 pc) to explain the large scale jet (size motivated by radio image, parameters limited by equipartition condition)
- Computed with agnpy code https://github.com/cosimoNigro/agnpy



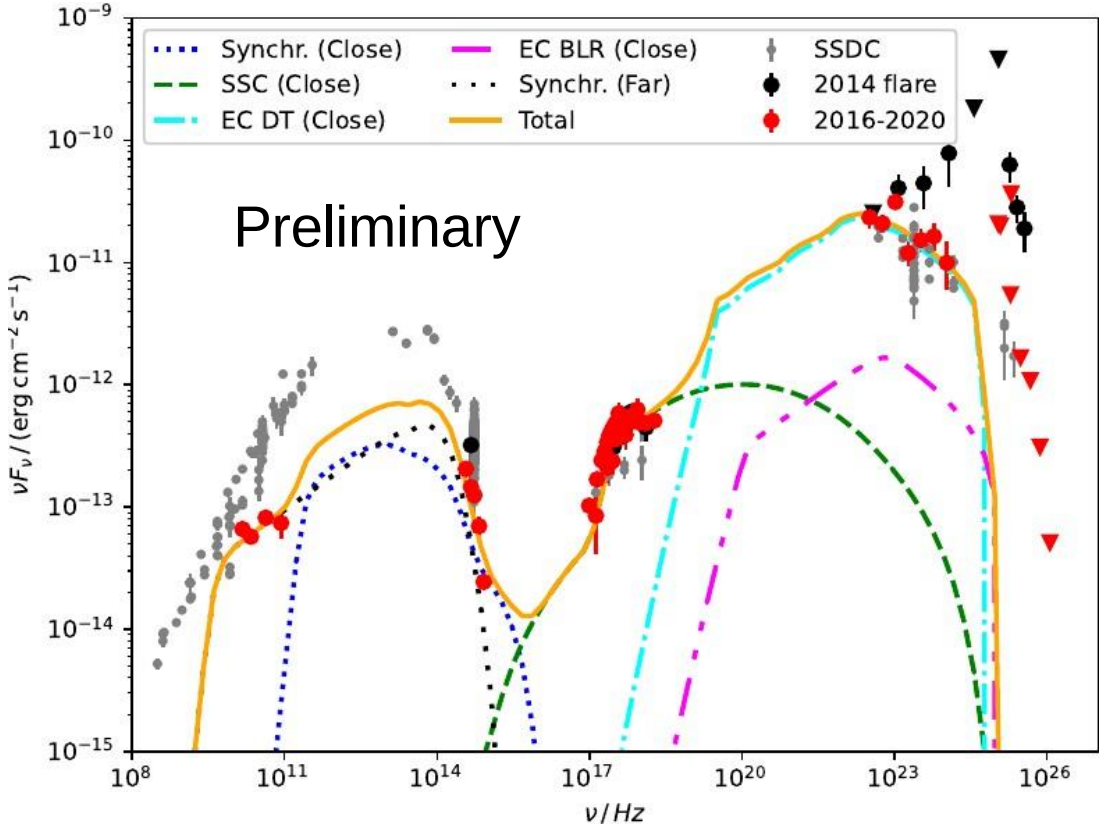
Broadband SED

- Comparing low state (red) with 2014 flare (black):
  - Slightly lower optical emission
  - GeV emission slightly lower but much softer
  - VHE gamma ray emission constrained at the level at least an order of magnitude below the flaring one
- In grey historical data from SSDC



Broadband SED

- Low energy bump: mostly synchrotron emission of the “Far” region (connected with the “jet” component seen in radio) with a contribution at optical-UV from the “Close” component
- X-ray emission – explained as SSC of “Close” component
- GeV emission explained as external Compton (EC) on Dust Torus (DT) photons and on the broad line region (BLR)



Conclusions

- 4 years of MWL monitoring of the only known at VHE gamma-ray energies gravitationally lensed blazar
- Improved lens model and measurement of column density of absorbing material in the lens galaxy
- Broadband low-state emission fitted with a two zone model with GeV emission explained as EC on DT radiation and X-ray emission stemming from SSC process
- Paper in the MNRAS review process